A Technical Overview of the Bourgoyne and Young Model's Development

Samuel S. Anderson*[1] & Andrew A. Isaac[2]
, Faculty of Petroleum Engineering and Technology, Department of Petroleum Engineering, Sheffield, UK

ABSTRACT

The early concepts of drilling optimization was dated back to the 1958's but have only been a viable for rotary speed, Weight on bit and rate of penetration (R-W-N) models followed by more efficient models as Bourgoyne and Young models. Improvements in drilling optimization around the world continue to focus on accuracy and efficiency over decades via different criteria's and disciplines. The objective of this paper is to review Bourgoyne and Young model development sequences together with area's need to be improved. Studies have been classified depends on it is scope directions to three groups: Multiple Regression Approach Group; Alternative Mathematical solutions group and Accuracy Improvement group for easy identification of added values together with critical need to be improved to each scope individually. Although these groups are not really separate from each other results showed lack in solving the shortage of bit wear information for all data points except end of bit run. Also there was a mostly absence of simulator application and scenario's for more strong verifications and accuracy.

KEYWORDS: Bourgoyne and Young; classification; bit wear information; simulator.

1. INTRODUCTION

Many detailed and effective research studies for different areas and disciplines have been performed in the area of drilling optimization since 1950th up to date mainly aiming safe, environment friendly, less hole problems and minimum expenditure well construction **Tuna Eren (2010)**. Early drilling optimization researches considered only (R-W-N) under condition of perfect cleaning together with neglecting depth effect; as model introduced by Maurer 1962 and developed by Bingham (1965). Over the following decades; many efforts have been exerted to optimize drilling through different criteria's and from different disciplines considering both controllable and uncontrollable variables and it is relationship with rate of penetration **Wee and Kalogerakis (1989)**. Mathematical drilling optimization models have been developed over last decade considering available technology. Starting from previous simple model together with manual applications such as excel, computer high level programming languages, real-time and recently artificial neural net work (ANN). One of the important steps is to identify relationship between drilling variables using one of proposed mathematical drilling models. Although new rate of penetration mathematical model with 100% accuracy have not been achieved yet; but some early studies or proposed models is considered as basis for most of drilling optimization researches. Up to date **Bourgoyne and Young model (1974)** considered as one of the best proposed models due to its large number of investigated drilling parameters.

2. MODEL THEORY

Bourgoyne and Youngs' model (**1974**) is linear relationship between rate of penetration and eight of drilling variables based on statistical synthesis of the past drilling parameters as the following equation: $\frac{dD}{dt} = Exp\left(a_1 + \sum_{j=2}^{8}(a_j\, x_j)\right)$ …….. (1)

The effect of formation strength coefficient is represented by "a_1" which is inversely proportional to natural logarithm of the square drillability parameter "S" as the following Maurer equation (**Maurer, 1962**):

$$R = K\frac{NW^2}{D^2S^2} \quad \text{…….(2)}$$

It is also includes the effects of penetration rate parameters that are not mathematically modeled yet such as the effects of drilled cuttings; solids content; efficiency of the rig equipment/material, crew experience, and service

contractors' efficiency. The equation for the formation strength related effects are defined as the following equation:

$$F_1 = e^{a_1} \text{……..(3)}$$

There are two functions allocated for the consideration of the formation compaction over rate of penetration. The primary function for the effect of normal compaction trend is defined by "F_2" as given in the following equation:

$$F_2 = e^{a_2 x_2} = e^{a_2(10000-D)} \text{…….(4)}$$

The other function considered to have an effect over the penetration rate in regards of the formation under compaction in abnormally pressured formations which is defined by coefficient "F_3", as the following equation:

$$F_3 = e^{a_3 x_3} = e^{a_3 D^{0.69}(g_p - 9.0)} \text{…….(5)}$$

The effect of pressure differential across the hole bottom on penetration rate is defined by the following equation: $F_4 = e^{a_4 x_4} = e^{a_4 \mathrm{D}(g_p - \rho_C)}$ ..... (6)

The term F_5 sub function is considered as the following equation which describing bit model:

$$F_5 = e^{a_5 x_5} = e^{a_5 \ln\left[\frac{\left(\frac{W}{d}\right)-\left(\frac{W}{d}\right)_t}{4.0-\left(\frac{W}{d}\right)_t}\right]} \text{..... (7)}$$

The term F_6 represents the effect of rotary speed on penetration rate as the following equation: $F_6 = e^{a_6 x_6} = e^{a_6 \ln\left[\frac{N}{100}\right]}$ ..... (8)

The term F_7 represents the effect of tooth wear on penetration rate as the following equation: $F_7 = e^{a_7 x_7} = e^{a_7(-h)}$ ..... (9)

The term F_8 represents the effect of bit hydraulics on penetration rate as the following equation: $F_8 = e^{a_8 x_8} = e^{a_8\left(\frac{\rho q}{350 \mu d_n}\right)}$ ..... (10)

Above equations defined relationship between penetration rate and the other drilling variables, but constants from a_1 to a_8 must be determined before this equation can be applied through multiple regression or any other mathematical solutions; then optimum weight on bit and rotation per minutes could be determined using the following equations:

$$\left[\frac{W}{d_b}\right]_{opt} = \frac{a_5 H_1 \left(\frac{W}{d_b}\right)_{max} + a_6 \left(\frac{W}{d_b}\right)_t}{a_5 H_1 + a_6} \text{ ..... (11)}$$

$$[N]_{Opt} = 60 \left[\frac{\tau_H}{t_b} \frac{\left(\frac{W}{d_b}\right)_{max} + \left(\frac{W}{d_b}\right)_{Opt}}{\left(\frac{W}{d_b}\right)_{max} - 4.0}\right] \text{..... (12)}$$

As (a_1) is formation strength parameter; (a_2) is exponent of the normal compaction trend; (a_3) is under compaction exponent; (a_4) is pressure differential exponent; (a_5) is bit weight exponent; (a_6) is rotary speed exponent; (a_7) is tooth wear exponent; (a_8) is hydraulic exponent; (X_2) normal compaction drilling parameter; (X_3) under compaction drilling parameter; (X_4) pressure differential drilling parameter; (X_5) *bit* weight drilling parameter; (X_6) rotary speed drilling parameter; (X_7) tooth wear drilling parameter; (X_8) bit hydraulics drilling parameter; (d) is bit diameter in; (D) is depth ft; (gp) is formation gradient; (ρ_C) is equivelant circulating density; (N) is rotary speed; (h) is tooth wear; (ρ) is mud density; (q) is flow rate; (μ) is viscosity; (d_n) is nozzle area; (H_1) is constant that depends on bit type; $\left(\frac{W}{d_b}\right)_{max}$ is bit weight per inch of bit diameter at which the bit teeth would fail instantaneously 1,0001b/in and $\left(\frac{W}{d_b}\right)_t$ is threshold bit weight at which the bit begins to drill, 1,000 lb/in.

Model Review

Bourgoyne and Young model introduced in 1974 to improve accuracy for previous models; dealing with well site monitoring system; multiple regression have been proposed for drilling data taken over short period (Condition: minimum 30 data points to be used in analysis to get reliable values for eight unknown drilling variables) and model mainly proposed to determine optimum bit weight, rotary speed and bit hydraulics. Since

1974 up to date; researchers consider Bourgoyne and young model as one of most important rate of penetration (ROP) models. Researchers work reviewed below are work on it and contribute to develop the model looking for rooms of improvements to match their areas conditions from different points of view, studies on this area have been divided to three groups depends on scope of studies for easy sequencing contribution and added values for each study individually.

Multiple Regression Approach

This group applied Bourgoyne and Young Model with eight sub functions and multiple regressions for specific area: **Emad A. Al-Betairi, Mohamed M. Moussa and Saud AL-Qtaibi (1988):** applied Bourgoyne and Young model to optimize drilling through multiple regressions using data collected from three wells in Arabian gulf area. Statistical (SAS) package have been used to determine eight unknown coefficients with correlation matrix, negatively correlation was found ((X_2), (X_3, X_2) (X_5) then (X_5) and (X_6) which indicated to presence of multi co-linearity. Statistical study was performed through F-Value and R-Squere which indicate unreal result due to presence of multi co-linearity. T-Test static have been selected for more reliable results. Authors selected first well alone and then other two wells; regression analysis have been carried out; five out of eight coefficients have negative values as regression results although R^2 and F shows model reliable. Bourgoyne and Young model is considered valid for this area as a result of statistical study together with requirement for more data

points for reliable parameter estimation. Usage of SAS package to perform multiple regression analysis is considered as innovation; but only 17 data points have been used instead of at least 30 points as proposed by Bourgoyne and Young. This considered as one of the main reason for presence of multi collinearity.

Same data limitation scenario have been repeated by **Sonny Irawan and Irawan Anwar (2012),** they applied Bourgoyne and Young to determine optimum weight on bit using data taken from Kinabalu East-1 well – Malaysia as case study. Multiple regression have been applied to determine eight unknown coefficients using limited data points (25points), optimum weight on bit have been determined and Drillsim500 simulator have been used for verification purpose. ROP actual against predicted have been plotted with big different between two curves for first eight points and distance become close for other points. Only 25 data points from one well have been used which led to out of range coefficients, more over only weight on bit have been optimized without rotation per minutes or bit wear, strength of this study is using DrillSim500 for verification as it consider one of best simulators.

On the other hand **Masoud Cheraghi Seifabad and Peyman Ehteshami (2013)** applied Bourgoyne and Young model for Ahvaz field which located in southeast Iran using data collect from fifty oil wells to offer suitable empirical equation for this area to speed up penetration rate for four formations (Agha Jari, Gachsaran, Asmari and Sarvak). Introduced that the model for Ahvaz field can predict formation boundaries, usable, generalized, predict drilling rate and drilling time and to choose optimum bit weight and bit rotation. Bourgoyne and Young model have been applied together with multiple regressions. Acceptable result have been achieved due to large number of data points (50 wells) more over wide range of data points allow them to eliminate bit type effect (as it is ignored in the model) through using similar bits for each structure.

Kutas D. T., Nascimento A., Elmgerbi A. M., Roohi A., Prohaska M., Thonhauser G. and Mathias M. H. (2015) applied Bourgoyne and Young model for pre-salt layers which are located close to shores of Brazil and on the other side of Atlantic Ocean close to shores of Angola. Excel 2010 and Oracle Crystal Ball Version 11.2.2 software's have been used together with field data to determine coefficients with lower and upper boundaries in terms of actual measured ROP value. Then coefficients were recomputed using Crystal Ball software targeting R-Square to one for best possible fitting to actual field ROP data, while keeping normalization factors unchangeable. Relative error shows better matching with value of 0.46. Other academic sources were investigated using previous two simulations together with same normalization factors and get relative error with value 0.266 which it was acceptable value. Bourgoyne and Young have been applied as it is under harsh situation for both pre-salt layers for high pressure high temperature wells without model development to look for improvement before application to match model with area condition.

Same new application without model modification scenario have been repeated by **Dimas Taha Maulana and Marbun B. T. H. (2015)** applied specific energy and Bourgoyne and Young models for six volcanic geothermal wells at the Altered Andesite Breccias lithology located in Indonesia. Altered Andesite Breccias lithologies have been divided to two soft and hard intervals parts. Then specific energy have been computed and plotted in order to optimize bit selection; thus one bit for each interval were selected as optimum bit run. Bourgoyne and Young eight unknown coefficients have been determined using multiple regressions (a_1, a_3, a_7 and a_8 are negative values while a_5 and a_6 where positive values). Authors' decision is to continue application with this result as target to determine optimum weight on bit and rotary speed. Moreover, difficulties to get additional data due to limitation of drilled wells for study area. Optimum weight on bit and rotary speed has been determined through Bourgoyne and Young model for two bits run. The determination of earlier points were specified by using specific energy model; thus values of both optimum weight on bit and rotary speed have been correlated through cost per foot versus weigh on bit and rotary speed graphs. Bourgoyne and Young model have been applied as it is for volcanic geothermal application assuming that drilling parameters is same for both applications. The critical question was "is the drilling parameters have the same relationship in both applications?". Moreover only ten data points have been considered which lead to negative values for some of the eight unknown coefficients.

Mahmood Bataee, Mohammadreza Kamyab and Rahman Ashena (2010) conducted study for Shadegan field which is consist Asmari formation as main reservoir, Gachsaran formation which is consists of seven subformations, Mishan and Aghajari formations. The study considered three different hole sizes 17-1/2", 12-1/4" and 8-1/2" holes and three different ROP models (Bingham, Bourgoyne and Young and Warren Models). Bingham model shows poor result in all sections due to neglecting of depth effect, warren model shows better

result for 7" section and Bourgoyne and Young model shows good result for both 13-3/8" and 12-1/4" sections and acceptable result for 7" section. PDC bits data have been applied for both Bingham and Warren model; while considering Bourgoyne and Young model is not fit to PDC. Better results could be achieved if modified Bourgoyne and Young model for PDC bits as introduced was used by **Reza Ettehadi Osgouei (2007)**. The following graph explains number of data points for each of mentioned authors, figure (1).

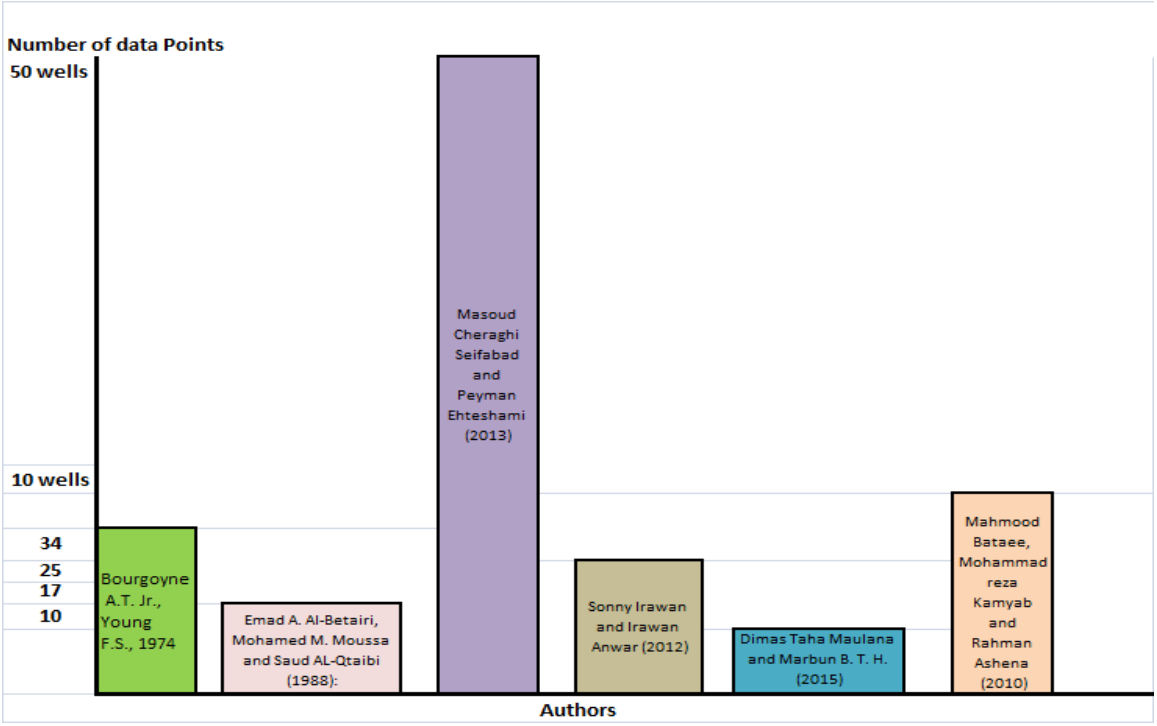

Figure (1): Applied Data Points for Multiple Regression Developed Models

3. ALTERNATIVE MATHEMATICAL SOLUTIONS

Four papers have been applied Bourgoyne and Young Model with alternative methods to determine eight coefficients to overcome data limitation constrains. These papers sequentially complete each other using nine wells which where have been drilled in Khangiran gas field. **Bahari A. and Baradaran A. S. (2007)** applied

Bourgoyne and Young model for nine wells of Khangiran gas field using different four techniques to determine eight unknown coefficients to overcome data limitation constrain. Multiple Regression as proposed by Bourgoyne and Young, Linear least square data fitting with non-negativity constrains, Non-linear square data fitting with Gauss-Newton method and Non-linear square data fitting with trust-region method. Selected nine wells data were divided for each formation individually, ROP software have been written using MATLAB and then eight unknown coefficients were computed for four mentioned method and each formation. Trust-region shows meaningful result despite the lower accuracy in comparison with other method. Trust region method is considered successful alternative solutions as it is not limited to number of data points as innovation. Moreover applied four different mathematical methods led to more strong verifications.

Same area and data as well have been used by **Bahari M. H., Bahari A., Nejati F. M, Rajaei R. and Vosoughi-V B. (2008):** Bourgoyne and Young model have been applied as it is (with multiple regressions), eight coefficients result gave negative values or zero which it has physically meaningless. Genetic algorithms have been applied to find out optimum unknown eight coefficients. Verifications for obtained values of (a_1) to (a_8) have been obtained through comparison between coefficients values which determined using multiple regressions, trust region and generated a logarithm. Study showed meaningful results, strong verification and more accuracy through comparison between different three mathematical models.

Same authors **Bahari A. and Baradaran S. A. (2009)** continued looking for more improvement through comparison of field data and mathematical optimization together following the same previous two papers. Data preparation have used three stages to be applied considering cost per foot, specific energy and penetration rate as formation correlations have been carried out. The cost per foot, specific energy and penetration rate have

been plotted against depth to consider optimum controllable parameters for points have lowest specific energy, lowest cost per foot and highest rate of penetration. Bougoyne and Young model have been applied to optimize drilling points for selected intervals through identifying coefficients using Matlab program with genetic algorithm, optimize hydraulic, determined maximum mechanical energy considering hydraulic energy, modeled bit wear rate for selected bits and made combination of comparative and mathematical optimization techniques. Bit type effects have been eliminated using comparative optimization method through plots of ROP; specific energy and cost per foot against depth. On the other hand the main concern is to keep the model only for tri-cone bits, which led to unavailability to apply the model for some intervals indicated by comparative optimization result due to usage of PDC bits.

Bahari Mohamad Hasan, Bahari Aboozar and Moradi Hamidreza (2011): The same previous three papers and its data have been used with consideration of papers results. Bourgoyne and Young model using genetic algorithm to find the eight unknown coefficients in order to get physically full coefficients meaning. The authors' proposed general regression neural network (GRNN) to expose unknown complex relationship between drilling rate and eight sub functions and high accuracy of estimated rate of penetration, as they inter calculated coefficients as input and get ROP as output of GRNN. The authors' test utilized intelligent ROP predictor using remaining data set (25%) using same previous procedure for 1000 times and additionally calculated the mean squared error (MSE) for each formation. Fuzzy-SA and BAY with trust region have been used and the percentage improvements have been determined for comparison purpose. Proposed GRNN to uncover functions relationship was main strength of the study and more over verification have been conducted through three different methods. But the developed model was still excluding PDC bits type data points.

Dan Sui, Roar Nybǿ and Vahid Aziz (2013) applied Bourgoyne and Young model based on real data collected from North Sea wells. Moving-window method has been applied to reduce model error through continuously calibration of eight unknown coefficients. This method makes the on-line computation feasible fast and the model became more robustness. Kalman filters have been applied to determine ROP in order to increase accuracy. A model predictive control (MPC) strategy employed the process model and was utilized to predict

the future response of a plant at each control interval to select optimum drilling parameters values and boundaries. Simulation have been conducted to two scenario's: firstly the model calculation was based on the model with a moving-window which showed it can predict true ROP trend considering the error between calculated and predicted ROP (non-negligible), on the other hand result generated by Kalman were much better as it removes noisy data and considered as one of the developed model strengths. Also the introductory of model predictive control (MPC) to control ROP and realize automation drilling considered as innovation. The following table (1) explains coefficient values using Multiple regression; trust-region and GA together with recommended bounds.

Table (1): Comparison of three different methods coefficient values with recommended bounds

Authors	a1	a2	a3	a4	a5	a6	a7	a8
Bourgoyne and Young Recommended bounds for each cofficient using Multiple Regression	0.5 - 1.9	0.000001 - 0.0005	0.000001 - 0.0009	0.000001 - 0.0001	0.5 - 0.2	0.4 - 0.1	0.3 - 1.5	0.3 - 0.6
Bahari M. H., Bahari A., Nejati F. M, Rajaei R. and Vosoughi-V B. (2008): five khangiran field using GA as the following								
Khangiran	1.5348	0.0001	1.16E-06	9.17E-05	1.9999	0.9835	0.4864	0.3
Kalat	0.8739	6.01E-05	0.0007	3.04E-05	1.9999	0.4	0.30003	0.3001
Abtalkh	1.3744	1.00E-06	1.01E-06	1.00E-06	1.9999	0.9999	1.4999	0.3
Shourijeh	0.5	0.0004	1.04E-06	6.14E-06	1.9999	0.9999	0.7147	0.3
Mozdouran	0.5593	1.0013	1.0073	1.0082	0.5	0.4	1.3403	0.3
Bahari A. and Baradaran S. A. (2009): five khangiran field using Trust-Region as the following								
Khangiran	1.7	0.00002	8.00E-07	1.10E-05	0.8	1	1	0.15
Kalat	1.3	1.80E-05	0.000002	1.00E-05	1.725	0.43	0.42	0.22
Abtalkh	1.22	8.00E-06	8.00E-07	1.00E-05	0.863	0.68	0.58	0.15
Mozdouran	0.66	0.000008	0.0000008	0.00001	0.8	0.4	1.35	0.15

4. ACCURACY IMPROVEMENT

Look for accuracy improvement and/or streamlining Bourgoyne and Young Model procedures. This group has the best contributions to develop the model through considering additional drilling parameters to increase model accuracy. **Reza Ettehadi Osgouei (2007)** develop a model from Bourgoyne and Young model though additional sub equations to improve and enhance the model for both tri-cone and PDC bits for horizontal and directional wells considering additional three sub functions related to hole cleaning in horizontal (build and vertical sections). Together with development for frictional tooth dullness equation have been developed. Data from several directional offshore wells drilled at Persian Gulf in 2004 was used, multiple regression have been done for vertical, build and horizontal sections. Eleven unknown coefficients have been determined and optimum weight on bit, rotary speed and cost per foot have been determined for dolomite and Anhydrite formation. Regression index of correlation was used. Validity indicated of proposed model with an error 25% when compared with field data. Innovated two important improvement at the same time were noticed as modified original Bourgoyne and Young model to be suitable for directional well through adding three sub equation to improve hole cleaning as one of main challenge for directional drilling **and** modified model to be suitable for both tri-cone and PDC bits. Main concern is using multiple regressions together with limited data points which led to high error percentage. Moreover missing of estimation for added value as a result of three additional drilling sub functions as there is no comparison between original and developed model results.
On line with previous research **Tuna Eren (2010)** applied Bourgoyne and Young model to three offshore directional wells in Mediterranean Sea through mud logging unit as real time data (two study wells and one development well model data). Real data piping between rig site and headquarter (through a macro code in excel written using visual basic language) have been proposed in order to minimize the cost and drilling problems as well, although data piping was not used in application but highlighted that this technique will be widely used in future. Three steps scenarios have been applied as firstly collected data which have been

applied as it is without correction. Then WOB have been corrected due to inclination and both WOB and RPM have been corrected using motor performance chart due to inclination angle and additional motor rotation respectively. **Lastly,** multiple regressions have been applied to determine eight unknown coefficients. The ROP have been computed for the three scenario's and standard deviation together with F-Test have been computed for three scenario's to show variance between actual and estimated ROP. Two scenario's corrections for both WOB and RPM shows considered contribution for result accuracy. The statistical finding with F-Test indicates data ended up have more accuracy and although there is no actual field test have been conducted to research result; but estimated cost reduction from actual drilling case is about 22%. Innovated correction for both WOB and RPM for directional drilling and motor performance chart respectively were illustrated. Unfortunately **Reza Ettehadi Osgouei (2007)** research result was not considered beside other two researches have almost the same scope of work for different areas. Multiple regressions concerns have been used together with limited data points which led to high error percentage **and** only F-Test have been used.

Tuna Eren, Ibrahim AlArfaj and Amar Khoukhi (2012) following **Eren (2010)** research results as basics to solve the main concern which considered as a result data set for only one well and only one kind of correction was applied. Another second well data have been added and three data correction types have been used. F-Test is added for comparison between actual and estimated ROP. In order to provide decision with best three models comparison have been carried out between traditional multiple regression result, extreme learning machine (ELM) and radial bases function net works (RBF) in terms of accuracy and speed. Nonparametric regressions have been used for both ELM and RBF, which it is regression without prior knowledge about the form function. Seven input data were used (depth, weight on bit, rotary speed, tooth wear, Reynolds number, equivalent circulating density and pore gradient). Outputs from the three models were compared based on training time, training accuracy, testing time and testing accuracy. Comparison result in terms of root mean square error (RMSE), standard deviation (SD) and absolute percent relative error (APRE) advised decision maker suggested choosing extreme learning machine (ELM) with sigmoid activation function as ROP prediction technique. Strong verification have been carried out through comparison between traditional multiple regressions and two types of artificial net works.

From other point of view **Sameera M. Hamad-Allah and Ali A. Ismael (2008)** applied Bourgoyne and Young model as it is using multiple regression to field data collected from forty wells drilled at three major fields in Iraq (data divided to three types: soft, medium and hard formations), threshold weight on bit assumed zero, model validation have been tested through three statistical techniques that are correlation coefficient (R), standard and predicted deviation versus observed data plots. Multiple regressions have been conducted with statistical package and appear negative values: three negative values for soft formation; two negative values for medium formation and one negative value for hard formation. Authors justified the negative values as it is due to presence of multi co-linearity or linear dependency between drilling variables, formation compressive strength and bit type has been not considered. Authors made modifications to Bourgoyne and Young model to

be more general and accurate as well as considering Galle, both Moore and Young models. Modified model have been re-used with same statistical package and techniques, got positive values for all unknown coefficients and low standard deviation values, thus proposed model have been validated using new four wells data successfully.

Combination of Galle woods model (tooth wear equation) and Moore and Young models for bearing life together with oil content function to modified Bourgoyne and Young model to eliminate effect of linear dependence considered as innovation. Moreover data collected from the forty well have been used together with multiple regression and were considered as one in strength.

On line with **Reza Ettehadi Osgouei (2007)** research it was founded **Falode O. A. and Agbarakwe C. J. (July 2016)** developed Bourgoyne and Young model for directional and horizontal wells considering additional three drilling parameters related to hole cleaning for horizontal, build and vertical sections respectively. Developed model has been used to determined the eleven model coefficients using genetic algorithm and predict ROP with an error (+/- 10%) using offshore data randomly selected from Khangiran field. Absolute error has been calculated for both multiple regression and genetic algorithm. Missing of exact added value for additional three sub function as percentage of development through comparison between original and developed model results

including ROP, accuracy and error was considered as concern. Also there was absence of previous research results as **Tuna Eren (2010)** and partially usage of **Reza Ettehadi Osgouei (2007)** research results.

Alum Moses A. O and Egabon. F (2011) developed semi analytical model based on Bourgoyne and Young drilling model to study relationship between rates of penetration with drilling rheological properties and to carry out these properties contributions through sensitivity analysis. Real time data have been collected from wells drilled in two fields in Niger Delta and divided to tow groups. One set was used to run regression analysis based on Bourgoyne and Young model for parameters contains differential pressure and other was used in verification. By assuming effects of all Bourgoyne and Young sub functions except differential pressure was considered constant and that ROP has exponential decrease with differential pressure. Three equations have been developed to express ROP in terms of annular pressure losses (plastic viscosity under both turbulent and laminar flow and the yield stress). Developed model validation have been carried out through excel program that have been developed based on above formulas and the ROP were plotted against differential pressure, annular pressure losses, plastic viscosity (laminar flow), plastic viscosity (turbulent flow) and yield stress. Depends on the R^2 concluded that Rate of penetration directly proportional to gel strength and inversely proportional to plastic viscosity (effect of plastic viscosity to ROP is more evident for laminar flow) and differential pressure. The net affect may not be significant except for annular pressure losses. Usage of semi analytical model to developed Bourgoyne and Young model considered as innovation although multiple regression have been applied together with limited data points and rheological properties contribution in the model mainly depends only for one of statistical measurement (R^2).

On the other hand only one research have been carried out on the opposite direction by **Wee W. and Kalogerakis N. (1989)** they conducted the study to evaluate ability of Bourgoyne and Young drilling model to predict rate of penetration with high accuracy for two offshore wells in Canadian east coast area. Analysis was conducted using four scenarios **(**original Bourgoyne and Young model, simple three drilling parameter model base on R-W-N, using five drilling parameters out of eight drilling parameters in original model and using extended model for Bourgoyne and Young model). Analysis showed significant poorer model than original Bourgoyne and Young model. Five parameter model shows significant reduction in required data by 40% and acceptable model predictive capability and extended model showed poorer result than that obtained by each well individually. Thus highlighted availability to reduced sub functions from eight to five sub functions without significant loss in predictive capability. Studying availability to reduce sub function to reduce amount of raw data by 40% together without significant reduction in predictive capability is considered innovation. Main concern is totally dependent to statistical tests analysis without comparison to coefficients physically meaningful and reliability, more over only two wells data have been used together with multiple regressions for verifications. The following chart explains comparison between above papers considering number of unknown coefficients, figure (2)

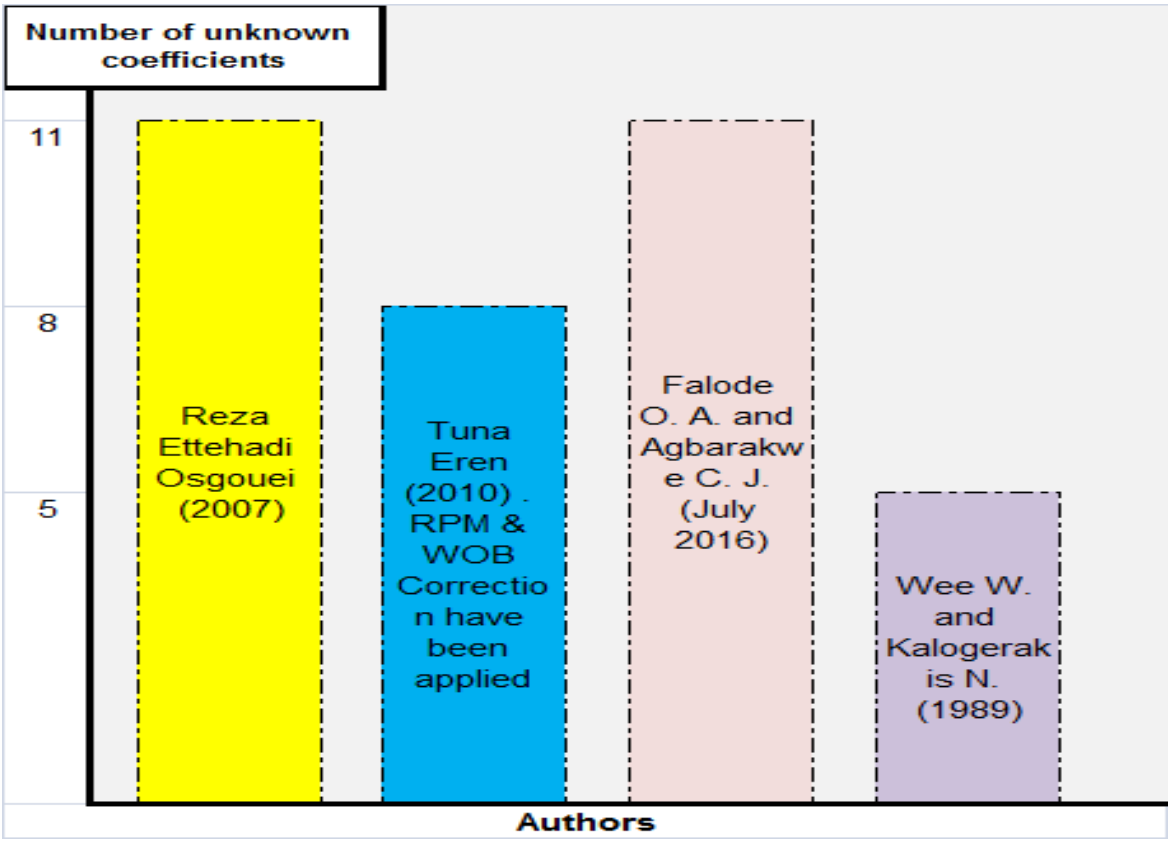

Figure (2): Unknown Coefficients Accuracy Improvement.

Neural net work is introduced to optimize drilling 1991 in which one of important steps is to identify relationship between drilling variables using one of drilling models. Some researchers consider Bourgoyne and Young model as one of the best models to define relationship. **Rahimzaeh H., Mostofi M., Hashemi A. and Salahshoor K. (2010)** applied Bourgoyne and Young model, Warren's model and neural net work model for two wells in one of Iranian gas field at Persian Gulf area. As two first models considered different parameters in order to decrease drilling expenditures and to predict ROP with different accuracies. Bourgoyne and Young have been developed for each formation individually neglecting bit type. Modified warren's model by Hareland (1993) have been used and developed for each bit run individually neglecting formation type. Available data have been divided to three parts (60% for training, 20% for validation and 20% for verification) and the Neural Net Work fitting tool (NFT) of Matlab software was used. Eight drilling parameters considered as input and ROP as outputs and correlation factor value was 0.847. Authors concluded that Warren's model showed less accuracy in comparison with Bourgoyne and Young model using genetic algorithm, highlighted that for this case accuracy of Warren's model was mainly affected by rock strength quality, while Bourgoyne and Young focuses more on drilling parameters. Moreover the application of neural net work for prediction of ROP showed more reliable result as it consider more parameters. Usage of Bourgoyne and Young model with genetic a logarithm, Warren's model and neural net work is considered as strength; but usage of limited data points for neural net work which led to slight improvement is considered as weakness.

Arabjamaloei R. and Shadizadeh S. (2011) studied Ahwaz oilfield (Iranian gas field) for thick shale formations (Pabdeh and Gurpi formations) to predict rate of penetration through development of model using artificial neural network (ANN), statistical and Bourgoyne and Young models with genetic algorithm applied to the same area for comparison purpose. To eliminate large amount of required input data combination of input data have been carried out depends on parameters relationship to be seven sub functions. Data filtration have been carried out to exclude odd values as preparation for ANN based on experience and through actual versus predicted ROP plots. Neural net work model shows better prediction compared to both statistical and Bourgoyne and Young model. Results have been generalized in other Iranian fileds and similar shaly formations in the

Middle East corresponding to Pabdeh and Shiranish formations. Generalization of result for model development to similar formations is considered as strength.

Naser Akhlaghi, Fatemeh Rezaei and Nima Akhlaghi (2012) applied Bourgoyne and Young model using artificial neural networks to six directional wells in Ahvaz field, in order to eliminate human error and increase accuracy as well. Data set have been divided to three groups (70% training purpose, 15% network validation purpose and 15% sensivity analysis). Square error method have been used and obtained using least square method the value 0.96704 (close to 1.0) indicated reliable network result. Using neural net work to optimize drilling for directional wells through applying Bourgoyne and Young model; together with approximately 4-2 million cycles of process and acceptable raw data which led to significant improvement was considered as strength.

5. CONCLUSIONS AND RECOMMENDATIONS

Bourgoyne and Young model considered one of best models to optimize drilling as original model considering eight drilling variables. Depends on scope directions; researches have been divided to three groups:
Multiple Regression Approach Group: applied model as it is together with data limitation as main constrain for different area's looking to make it suitable for specific area neglecting difference conditions comparing to the original model condition. As a result it has less contribution to model development.
Alternative Mathematical Solutions Group: applying Bourgoyne and Young model using different mathematical methods to eliminate and overcome data limitation constrain. Some methods prove its success and others shows its limitations (genetic a logarithm method is best of alternative method as it give realistic and within arrange coefficients).
Accuracy Improvement Group: has the best contributions to develop the model through considering additional drilling parameters (such as hole cleaning). Modifying some of drilling parameters especially for directional wells and studied availability to reduce drilling parameters together with high accuracy and applying the artificial Neural net work (ANN) considering pervious benefits of later researches.
Considering both benefits and limitations of late researchers from their ancestor's results regardless their group or classifications:

- all researches looking for alternative solution methods to overcome data limitation and neglecting to look for rooms of improvement for multiple regression techniques.
- Most of researches applications used only tri-cone bits as original proposed model and there is a lack of verifications as it is significantly depends on statistical hypothesis tests together with absence of numerical simulation applications.

Recommendations are to:

- distribute bit wear equally or depends on drilled formations to overcome data limitation constrain using both tri-cone and PDC drill bits.

Consider numerical simulation applications together with statistical hypothesis tests for more strong verifications and direction towards to apply artificial neural net work considering previous benefits.

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